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Short communication

Effects of narrow base gait on mediolateral balance control in young and older adults

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ABSTRACT

The aim of this study was to examine the effect of narrowing step width on mediolateral (ML) center of mass (COM) kinematics and margin of stability (MOS) in young and older adults. Fourteen young and 18 healthy older adults were asked to walk on a treadmill at preferred speed, stepping on projected lines at their predetermined preferred step width (PSW) and at a 50% narrowed step width (NSW). Linear trunk accelerations were recorded by an inertial sensor, attached at the level of the lumbar spine and foot placement was determined from force sensors in the treadmill. Mediolateral peak-to-peak COM displacement, COM velocity and MOS within strides were estimated. Mean ML-COM displacement and velocity, which were significantly higher in older compared to young adults, were significantly reduced in the NSW condition while the variability of ML-COM velocity was increased in the NSW condition. A significant interaction effect of step width and age was found for ML-COM velocity, showing larger decreases in older adults in the NSW condition. Walking with NSW reduced the ML-MOS significantly in both groups while it was smaller in the older group. Although reductions of ML-COM displacement and velocity may occur as direct mechanical effects of reduced step width, the larger variability of ML COM velocity in the older adults suggests active control of ML COM movements in response to the reduced base of support. Given the effects on MOS, narrowing step width might challenge ML-balance control and lead to less robust gait especially in older adults.

1. Introduction

Mediolateral (ML) gait stability requires regulating the center of mass (COM) position relative to the lateral limits of the base of support (BOS). From this perspective, the ML margin of stability (MOS), which considers the ML-COM position and velocity relative to the lateral border of the BOS, can provide important information (Hof et al., 2005). Based on the simplifying assumptions of the inverted pendulum model for balance control (Hof et al., 2005; Winter, 1995), a smaller ML-MOS would indicate lower robustness to deal with sideward perturbations and hence a higher risk of instability, although empirical evidence to support this assumption is lacking (Bruijn et al., 2013). In addition, larger kinematic variability may increase the probability of exceeding the MOS and increase fall risk (Toebes et al., 2012). Perturbations of gait stability often elicit increased step width (SW) to maintain or increase the ML-MOS (Hak et al., 2012), but as a trade-off increasing SW entails energetic costs (Donelan et al., 2001).

Age-related balance impairments lead to an increased fall risk (Hausdorff et al., 2001; Tinetti and Kumar, 2010). In line with the above, older adults, especially older adults at risk of falling, often adopt an increased SW as a compensatory strategy (Maki, 1997; Schrager et al., 2008), while a narrow SW, among older adults, indicates increased risk of sideward falls (Ko et al., 2007) compared to falls in other directions. In young adults, walking with narrow steps reduced the MOS (Young and Dingwell, 2012). However, in older adults, a reduced ML-COM displacement and velocity were observed when walking with narrow steps (Schrager et al., 2008), which might have preserved the ML-MOS, although this was not calculated. Such a reduction of ML-COM displacement and velocity when walking with narrow steps might arise as a direct mechanical effect of the narrower SW, since narrower stepping would decrease the moment induced by the ground reaction force and consequently reduce ML body sway (Hof et al., 2007). However, it may also reflect a strategy to more tightly control the COM over the narrower BOS.

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We aimed to investigate the effect of narrowing SW on ML-balance control in terms of ML-COM kinematics and ML-MOS in young and older adults. We hypothesized that both young and older adults would show a decreased ML-MOS with narrow SW, in spite of reduced ML-COM displacement and velocity.

2. Methods

2.1. Participants

Eighteen healthy, community-dwelling older adults (ten females; mean age 73, SD 4 years; height 172, SD 10 cm; mass 63, SD 6 kg) and fourteen young adults (nine females; mean age 23, SD 3 years; height 174, SD 10 cm; mass 66, SD 10 kg) participated in this study. The local ethics committee approved the protocol (#2014-32) and participants gave written, informed consent before participation.

2.2. Experimental protocol

Participants walked on a split-belt treadmill (Motekforce Link, Amsterdam, The Netherlands) with two embedded force platforms. After a familiarization and determining their preferred walking speed (Mazaheri et al., 2014), they walked for 3 min to calculate their preferred SW. Then, they walked for 2.5 min under two SW conditions in which the distance between the two lines projected on the treadmill was set symmetrically relative to the midline of the treadmill at their preferred SW (PSW) or at 50% of their preferred SW (NSW). The participants were instructed to align the middle of their shoe with the line. During both trials, 3D linear accelerations of the trunk were recorded by an inertial sensor (Dynaport Hybrid, McRoberts B.V., The Hague, The Netherlands) attached at the level of the lumbar spine. A safety harness was used to support body mass in case of an impending fall.

2.3. Data collection and analysis

Ground reaction forces were recorded at 1000 samples/s. Subsequently, force data were low-pass filtered at a cut-off frequency of 5 Hz and anterior–posterior center-of-pressure (COP) data were used to calculate left and right heel strike (HS) and toe-off (TO) instants (Roerdink et al., 2008).

SW was calculated as the distance between the ML COP during left and right single-support phases (e.g., from left TO to left HS for right single-support). Mean and standard deviation (SD) of step time were calculated based on the intervals between heel strikes.

The inertial sensor was measured at 100 samples/s. Data were low-pass filtered at 20 Hz. Misalignment of the sensor relative to the vertical and direction of progression was corrected (Rispens et al., 2014).

Assuming that the inertial sensor movement equals COM movement, time-series of ML-acceleration were integrated to estimate ML-COM velocity and position (Floor-Westerdijk et al., 2012), which were both high-pass filtered with a cut-off frequency of 0.1 Hz to avoid drift. Then, the peak-to-peak ML-displacement and velocity were calculated within a stride and the mean and SD of these parameters were calculated over 120 strides.

Finally, the ML-position and velocity of the sensor were used to estimate the time-series of the ML-extrapolated COM position (ML-xCOM) (Hof et al., 2005), using a leg length of 53% of total body height (Drillis et al., 1964). Assuming symmetric gait, the peak-to-peak displacement of ML-xCOM within each stride was subtracted from the concomitant SWs averaged within each stride and divided by two to obtain an estimate of the ML-MOS (Hof et al., 2005).

2.4. Statistics

There were no violations of normality and homogeneity of variance assumptions, as checked by Shapiro–Wilk and Levene's tests. To test whether SW affects the means and SD of ML-COM displacement and velocity, ML-xCOM and ML-MOS in young and older adults, two factor (conditions [NSW, PSW] × age [young, older])

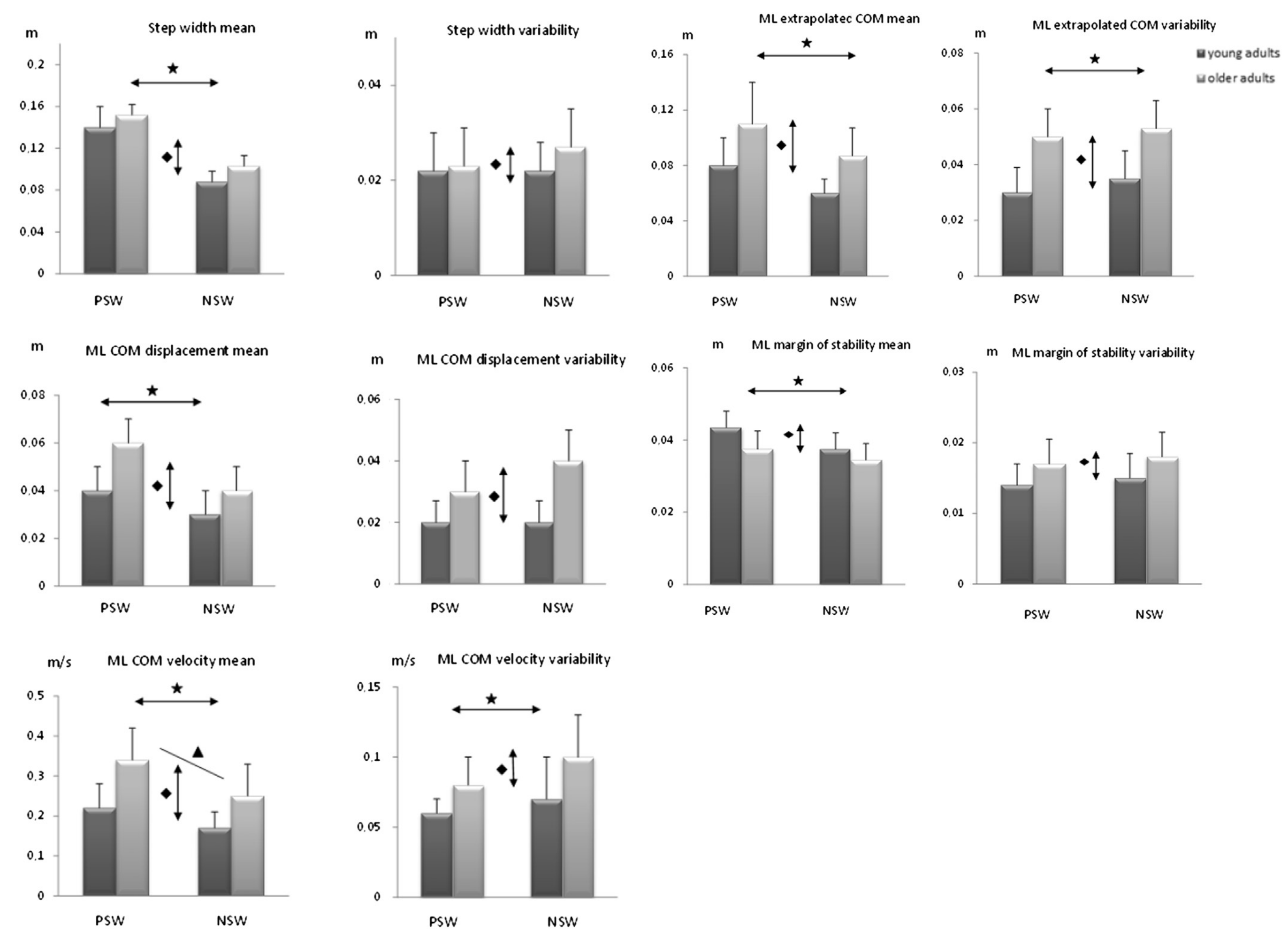

Fig. 1. The effect of preferred step width (PSW) and narrow step width (NSW) on ML-COM displacement and velocity, ML-xCOM and ML-MOS in young and older adults. The stars, diamonds and triangles indicate significant effects of step width, age and interactions of step width and age, respectively. The error bars represent standard deviation of mean.

mixed-design analyses of variance (ANOVA) were performed. If the interaction was significant, follow-up analyses were performed to compare SW effects between age groups. For all analyses, p-values < 0.05 were considered significant and statistical analyses were performed using IBM SPSS statistics 21.0.

3. Results

Preferred walking speed was 4.4 (SD 0.4) and 3.7 (SD 0.7) km/h in young and older participants, respectively, which was significantly different between groups, but the mean step time was statistically comparable between groups and within conditions and was overall 0.52 (SD 0.04) s. SW was larger ($p=0.020$) in older participants (Fig. 1). In the NSW condition, targeted SW was 50% of the PSW, but actual SW was 60% of PSW in both groups. SW variability was significantly larger in the older adults than in the young adults ($p=0.040$), but was not affected by imposed SW or by its interaction with age (Fig. 1).

Both young and older adults walked with smaller ML-COM displacement in the NSW condition ($p<0.001$), while it was larger in older compared to young adults in both conditions ($p=0.005$). ML-COM displacement variability was also larger in older adults ($p=0.003$). All participants walked with lower ML-COM velocity in the NSW condition ($p<0.001$) and ML-COM velocity was higher in older adults in both conditions ($p=0.001$). Importantly, the older adults showed a larger reduction of ML-COM velocity in the NSW condition compared to the young ($p=0.031$). COM velocity variability was higher in NSW than in PSW ($p=0.011$) and it was higher in older adults in both conditions ($p=0.007$) (Fig. 1).

The ML-xCOM amplitude was smaller in the NSW condition in both groups ($p<0.001$) and was larger in the older adults than in the young adults ($p=0.008$). The variability of the ML-xCOM amplitude was larger in the NSW compared to the PSW condition ($p=0.005$) and it was larger in the older adults ($p=0.006$). As a result, walking with narrower SW reduced the ML-MOS in both groups ($p<0.001$), while it was significantly smaller in the older group ($p=0.026$). Variability of the ML-MOS was not affected by SW ($p=0.088$); while it was larger in older adults compared to young adults ($p=0.035$). (Fig. 1).

4. Discussion

We examined effects of narrowing SW on ML-COM kinematics and ML-MOS in young and older adults. NSW decreased ML-COM displacement and velocity in both groups, with larger effects on ML-COM velocity in the older group. In addition, COM kinematics were generally more variable in the NSW condition and in the older group. As hypothesized, the ML-MOS decreased with narrower SW, irrespective of age. The smaller mean ML-MOS with NSW, which in older adults coincided with increased ML-MOS variability, indicates less robust gait and hence an increased risk of balance loss, especially in older adults.

Our results supplement previous findings of a decrease in ML-COM displacement and velocity with narrower SW in older adults (Schrager et al., 2008). The larger ML-xCOM displacement in our older adults led to a smaller ML-MOS, which indicates that the COM is closer to the margin of the BOS, which may increase the risk of balance loss and falling (Hof et al., 2005). The observed interaction effect of age and SW on COM velocity suggests that older adults used a more cautious movement strategy with lower COM velocity to maintain the COM within the narrower BOS in the NSW condition, yet the ML-MOS was slightly smaller in older adults in this condition. This in combination with the increased variability in ML-COM and xCOM kinematics also suggests that kinematics are actively adjusted to the imposed SW. Hence, while an association between frontal trunk COM kinematics and subsequent SW (Hurt et al., 2010) suggests predictive adjustments of SW based on kinematics, the present results suggest that the opposite also occurs, i.e., trunk kinematics are adjusted when SW is constrained.

The variability of SW and ML-COM kinematics were overall larger in older adults, possibly because of age-related neuromuscular changes that can increase sensory-motor noise (Shaffer and Harrison, 2007). This might explain why older adults prefer to walk with wider steps, to increase the ML-MOS and deal with larger ML-COM variability, despite associated increases in hip abductor activity (Kubinski et al., 2015) and energy cost (Donelan et al., 2001; Wert et al., 2010). The larger variability in ML-COM velocity that we observed in both groups with NSW suggests a higher risk of ML-balance loss in such a condition for any age.

Hip abductor muscles medially accelerate the COM during the stance phase (Pandy et al., 2010). Hence, decreased hip abductor strength with ageing (Johnson et al., 2004) might have led to less medial acceleration of the COM and subsequently larger and faster lateral ML-COM displacement in the older participants, compared to their young counterparts. Moreover, it suggests that older adults might even have more difficulties in controlling their balance if they are forced to adjust their kinematics to a smaller ML-BOS. The adjustment of the gait kinematics to the reduced BOS was reflected in the ML-MOS and its variability. In older adults in the NSW condition, the mean ML-MOS was 1.91 times the SD, while in the young, the mean MOS was 2.5 times the SD. A mean MOS of 1.91 SD implies that the probability of exceeding the BOS was 2.81% for the average older participant. This shows that walking with a reduced BOS challenges balance in older adults, and indeed impaired tandem walking is not uncommon in older adults and was shown to be a predictor of falling (Cho et al., 2004).

Some limitations need to be considered. First, the older adults' preferred walking velocity was slightly lower than that of young adults. As gait speed does not affect the ML-MOS (Hak et al., 2013, 2012), this difference is not expected to affect our main results. Second, we assumed a symmetric gait pattern and averaged out any possible step-to-step variability. Third, we used the averaged COP between HS and TO to estimate the BOS over steps. Although the actual BOS would be slightly larger than estimated here, using the lateral edges of the feet to define the BOS would likely not alter our main conclusions. Finally, a constant percentage of body height was assumed for leg length to calculate ML-xCOM in both groups; however, this percentage might be underestimated in older adults due to an age-related decrease in spine height. If so, we slightly underestimated the ML-xCOM and overestimated the ML-MOS in older adults.

In conclusion, the present study indicates that balance in the frontal plane is challenged in both young and older adults during narrow base walking. Despite reductions of ML-COM displacement and velocity to keep the COM within the BOS, the smaller mean ML-MOS combined with the larger ML-MOS variability indicates less robust gait in the older adults.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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